MEDICAL AND WORK PERFORMANCE PROBLEMS AT HIGH TERRESTRIAL ALTITUDES

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CCOEM OVERVIEW

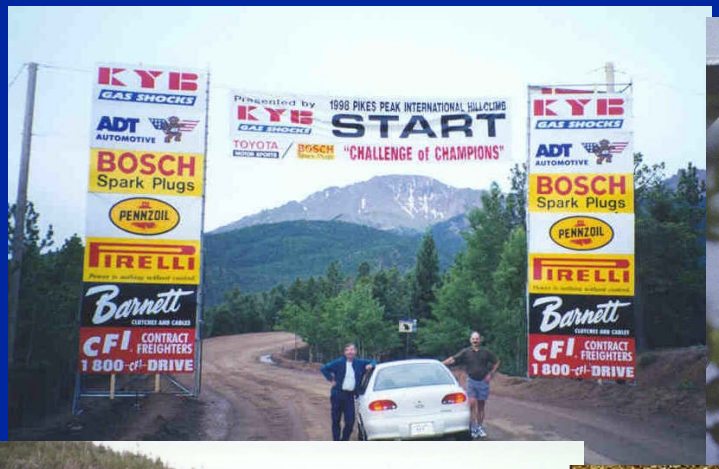
I. Mountain Environment

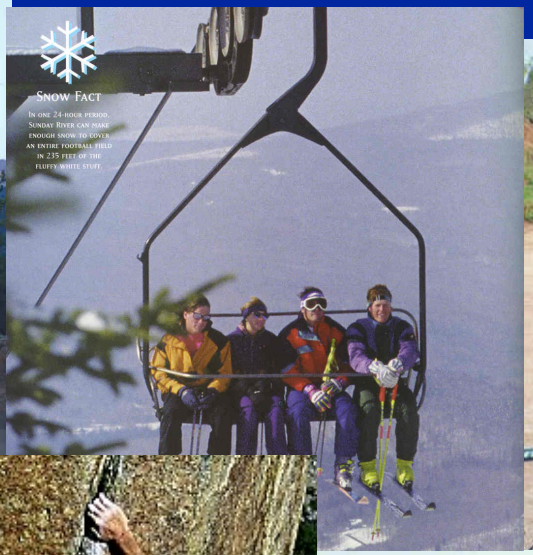
II. Altitude Acclimatization

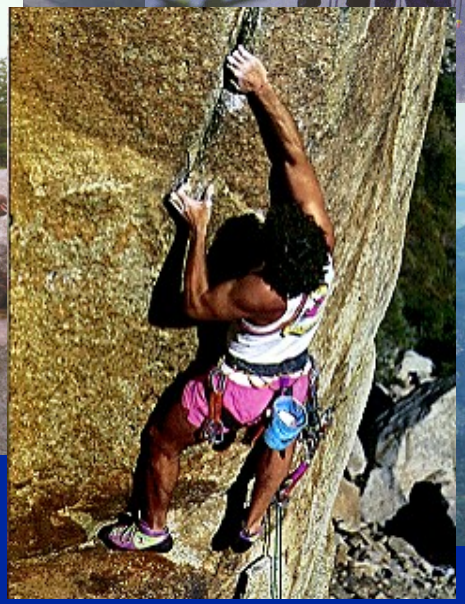
III. Work Performance

IV. Medical Problems

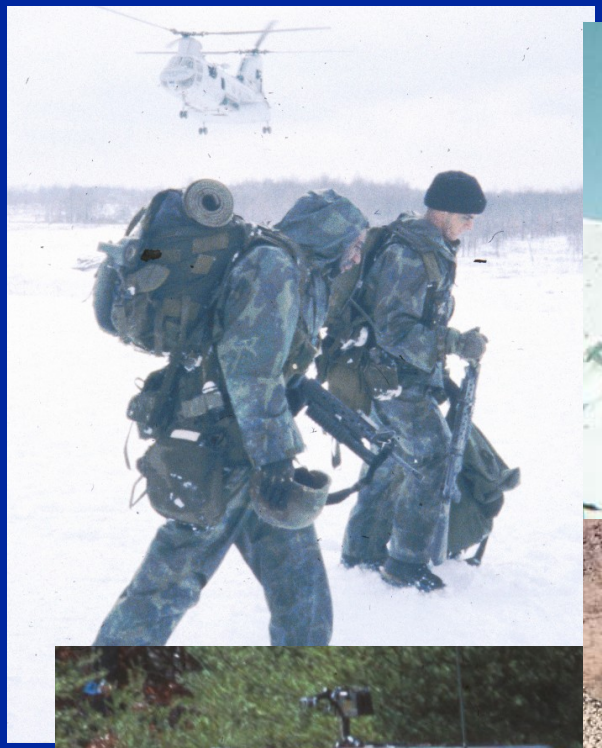
ACCESS AND USE OF THE MOUNTAIN ENVIRONMENT

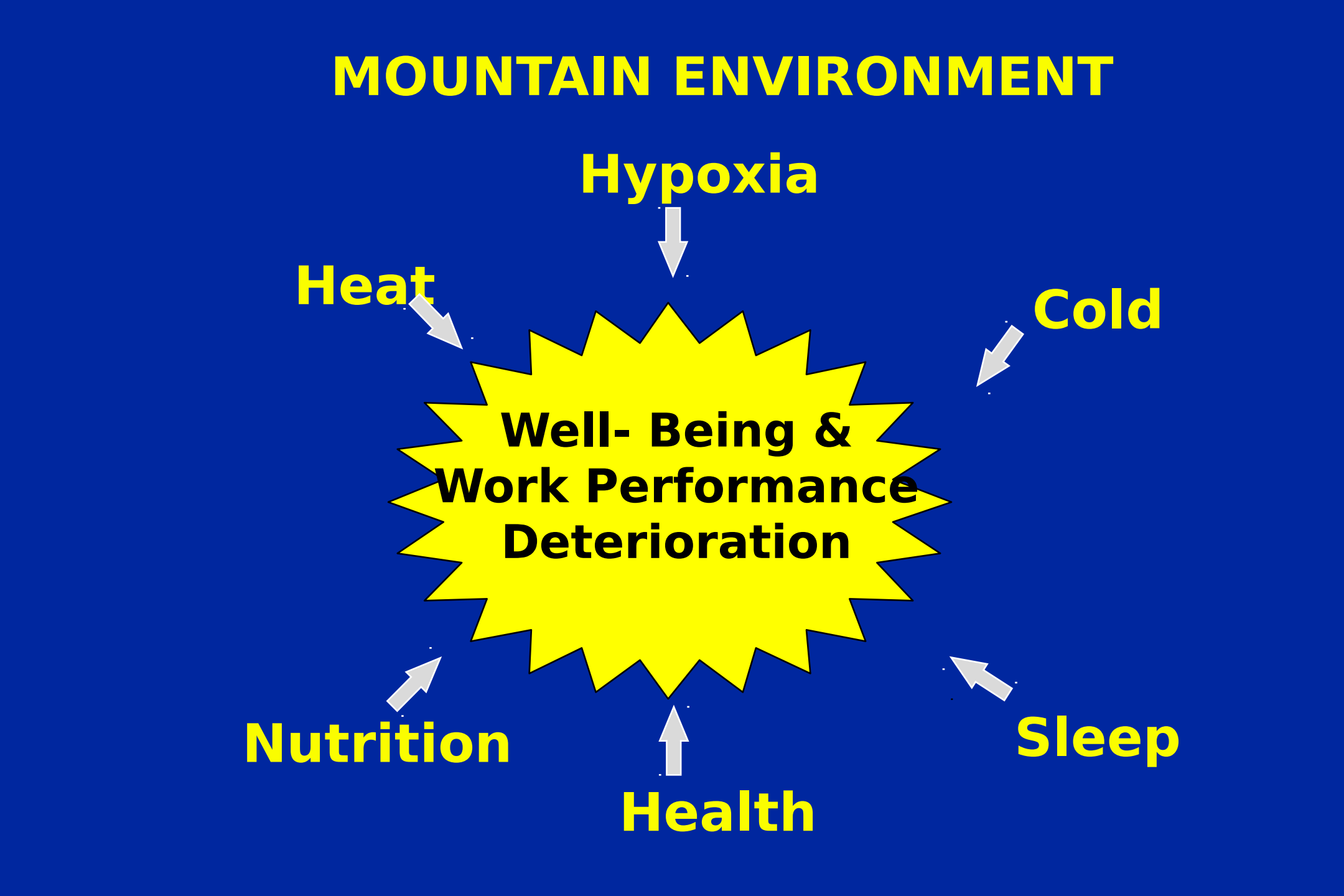



Snow Fact
In one 24-hour period, Sunday River can make enough snow to cover an entire football field in 235 feet of the fluffy white stuff.

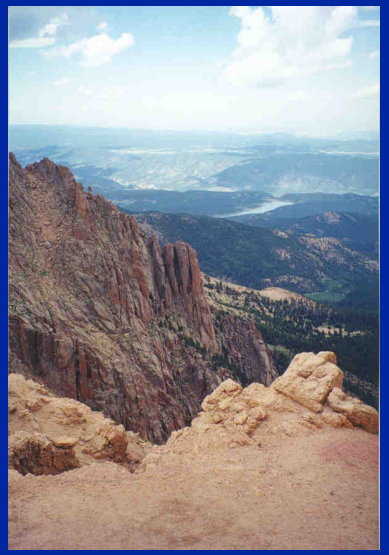


MILITARY OPERATIONS IN THE MOUNTAIN ENVIRONMENT




MOUNTAIN ENVIRONMENT
Hypoxia
Heat
Cold
Well- Being &
Work Performance
Deterioration
Nutrition
Health
Sleep

MOUNTAIN ENVIRONMENT
HEAT & COLD STRESS



Solar Load

Wind

Ambient Temperature

Low Humidity

Changing Climate

Clothing

Work Rate

MOUNTAIN ENVIRONMENT

Hypobaric Hypoxia

Unique to the mountain environment

ALTITUDE & BAROMETRIC PRESSURE OF SIGNIFICANT LOCATIONS

Altitude (ft)

30,000
25,000
20,000
15,000
10,000
5,000
0

Mt. Everest, Nepal (29,090
Qogin Feng (K2), (28,833 ft)
Aconcagua, Chile (22,833 ft)
Mt. McKinley, AK (20,320 ft)
Mt. Kilimanjaro, Tanzania (19,340
Pikes Peak, CO (14,110 ft)
Leadville, CO (10,152 ft)
Mt. Mitchell, NC (6,684 ft)
Denver, CO (5,300 ft)
Salt Lake City, UT (4,200 ft)
New Orleans, LA (0 ft)

760 600 400 200 0

Barometric Pressure (mm Hg)

MOUNTAIN ENVIRONMENT
HYPOBARIC HYPOXIA

$P_IO_2 = F_IO_2 \times P_B$ mmHg

At Sea Level:

$P_IO_2 = 0.209 \times 760 = 149$ mm

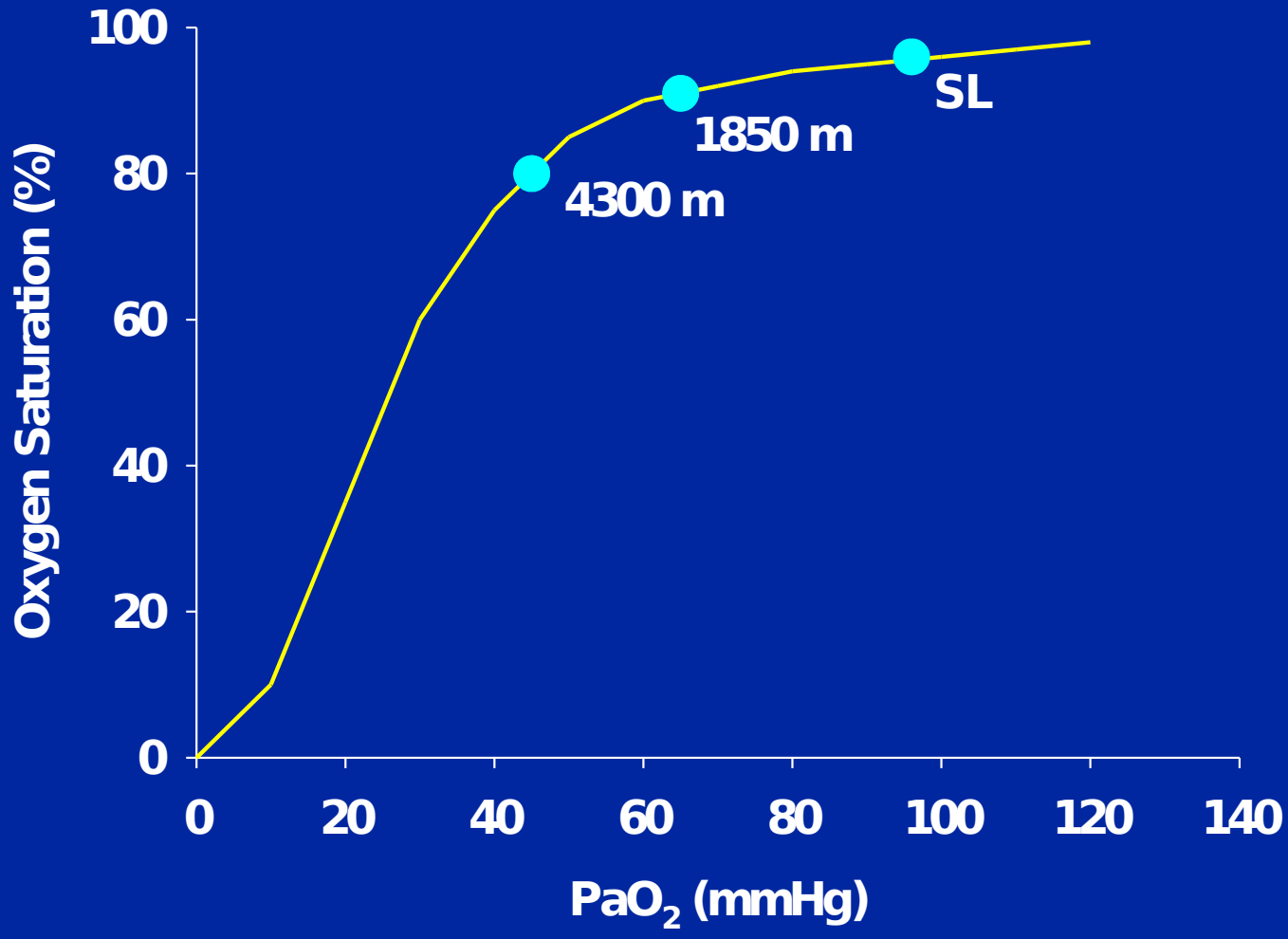
At Ft. Carson, CO:

$P_IO_2 = 0.209 \times 605 = 126$ mm

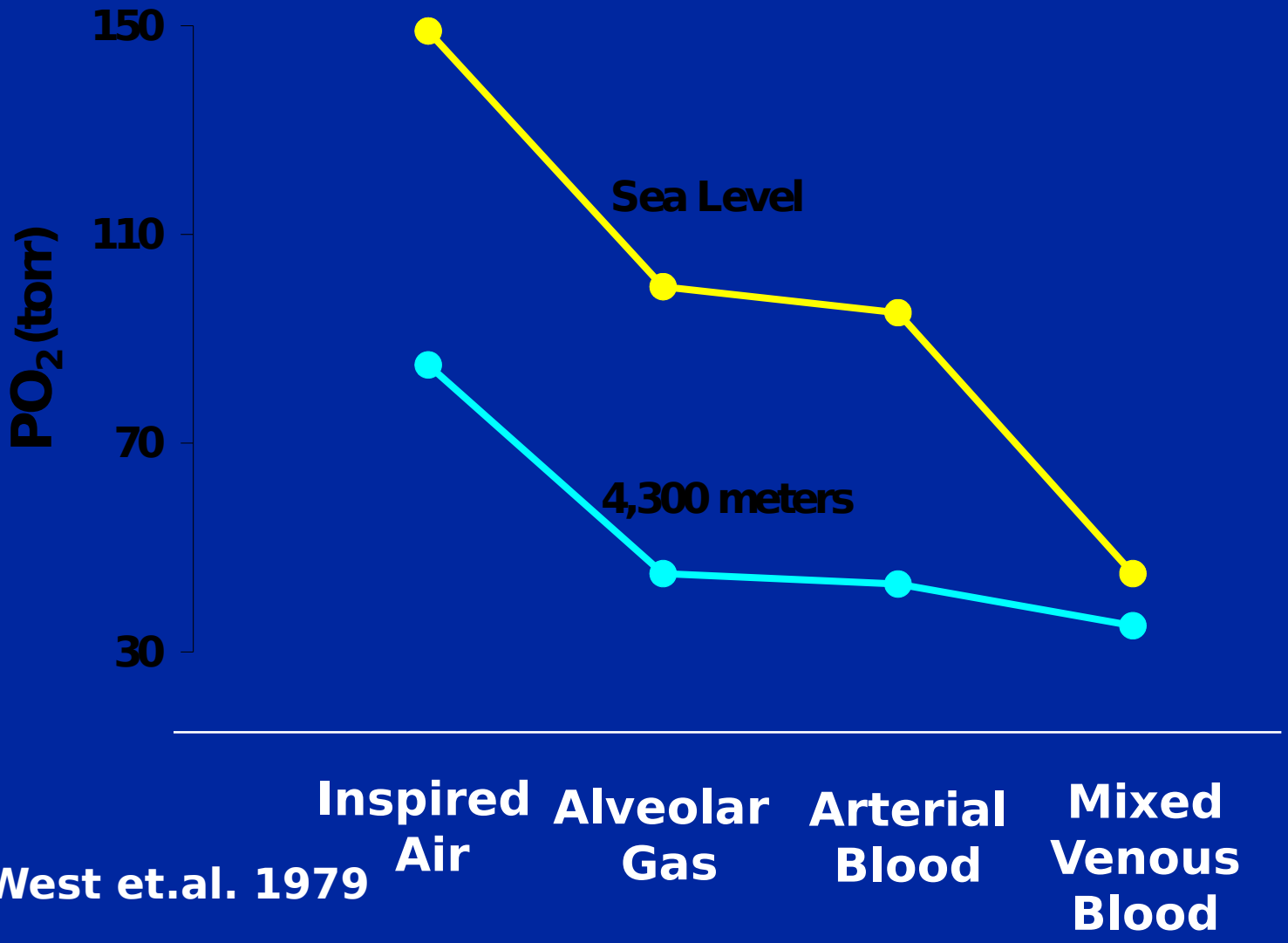
On Summit of Pikes Peak, CO

$P_IO_2 = 0.209 \times 446 = 93$ mm

EFFECT OF HYPOBARIC HYPOXIA ON ARTERIAL OXYGEN CONTENT

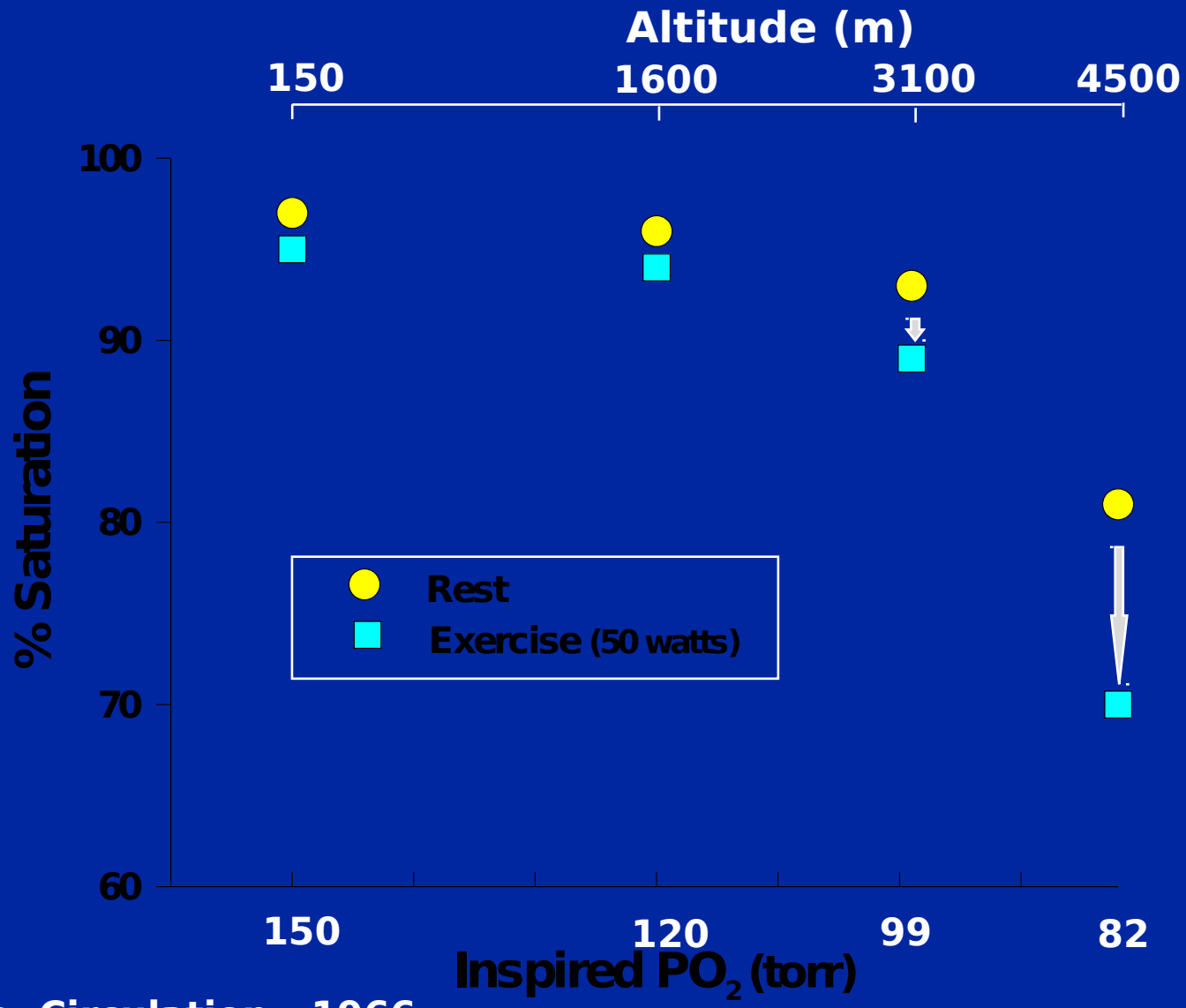


OXYGEN TRANSPORT CASCADE DURING REST AT SEA LEVEL & HIGH ALTITUDE



West et.al. 1979

ALTITUDE & EXERCISE EFFECTS ON ARTERIAL O_2 SATURATI



Banchero, Circulation., 1966

ALTITUDE ACCLIMATIZATION

STUDY OF HUMAN ACCLIMATIZATION TO HIGH ALTITUDE

World-wide, most frequently studied altitude is 4,000 -

ALTITUDE ACCLIMATIZATION BENEFITS

- Well Being - *Improved*
- Mental Performance - *Improved*
- *Sleep Quality - Improved*

- Submaximal Work Performance - *Improved*
- Maximal Work Performance - *Unchanged*

ALTITUDE ACCLIMATIZATION

MAJOR OUTCOME:

Increase oxygen delivery

MECHANISMS:

Increase ventilation
Increase hemoglobin concentration
Increase tissue oxygen extraction

VENTILATORY ADAPTATIONS TO ALTITUDE

Early:

PaO_2 < 60 mmHg stimulate peripheral chemoreceptors

Increases PaO_2, decreases $PaCO_2$

Hypocapnia blunts ventilation

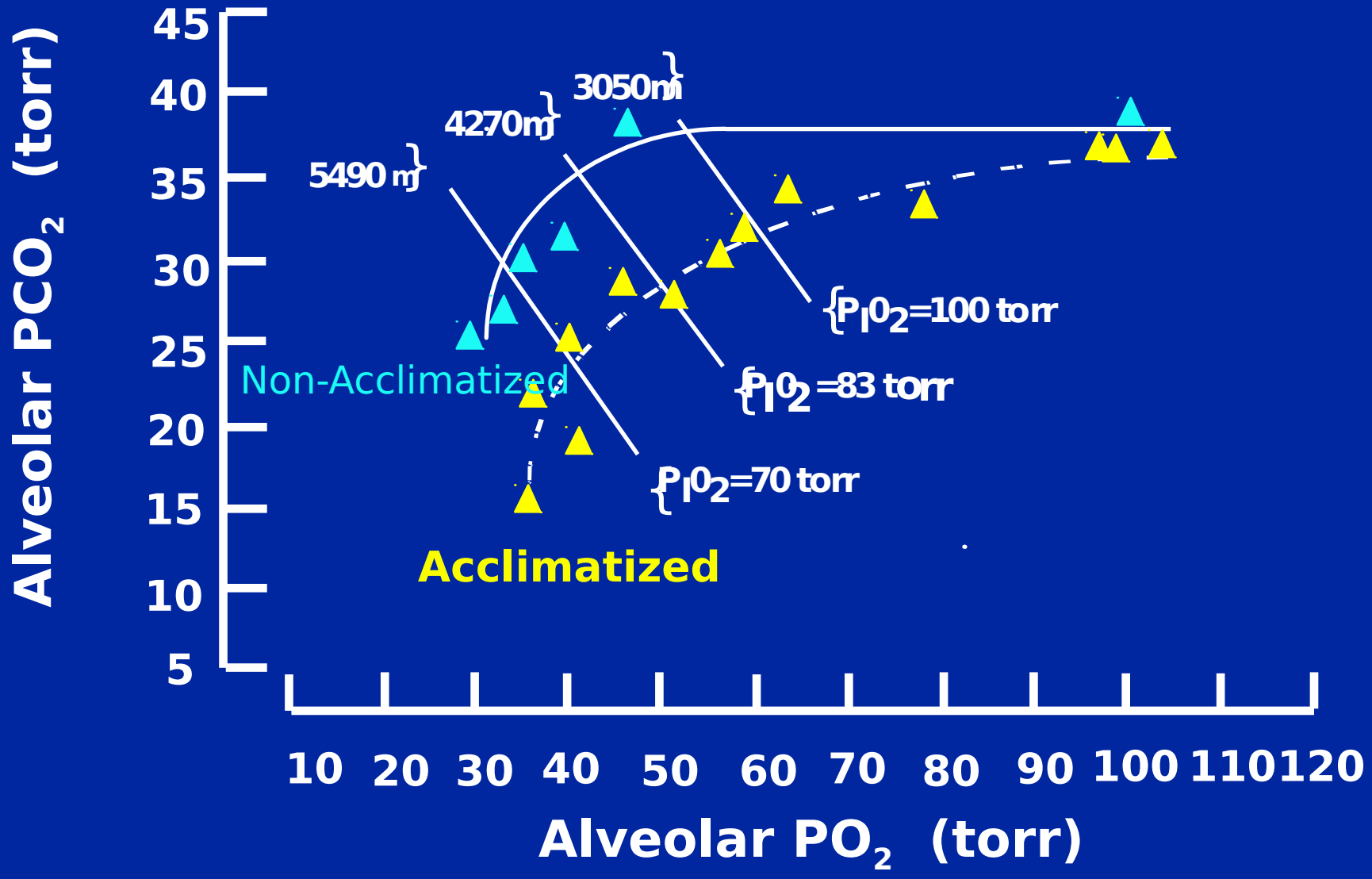
Hypoxic ventilatory depression blunts ventilation

1 - 12 days:

Central chemoreceptor resets to lower $PaCO_2$

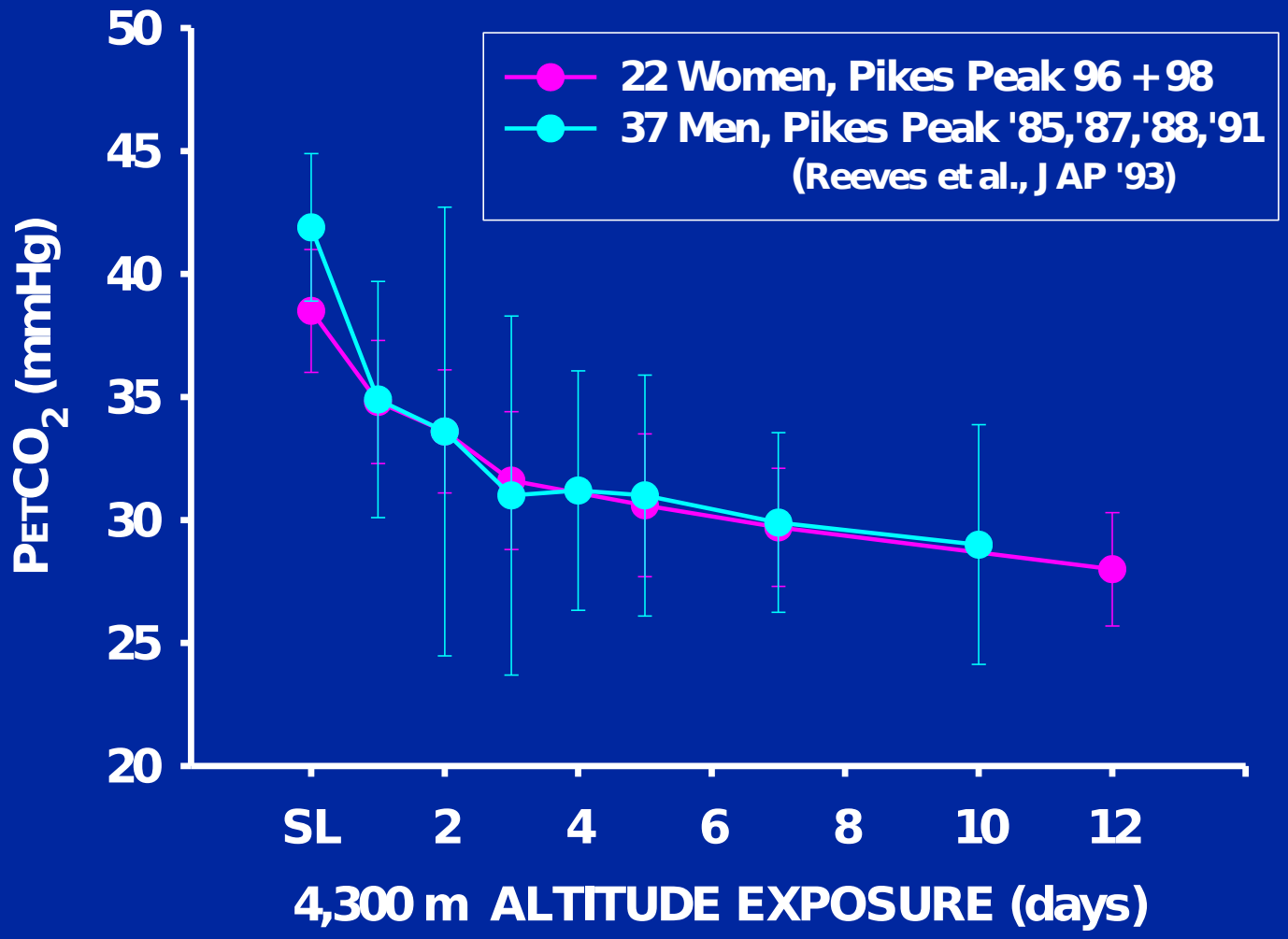
Renal excretion of HCO_3^-

VENTILATORY ACCLIMATIZATION TO ALTITUDE



Young & Young, Human Performance Physiology 1988

VENTILATORY ACCLIMATIZATION TO ALTITUDE
EFFECT OF GENDER



HEMATOLOGIC ADAPTATIONS TO ALTITUDE

Early:

- **Plasma loss increases [Hb]**
- **Total blood volume decreases**
- **Increased 2,3 DPG increases tissue O_2 delivery**
- **Erythropoietin stimulation**

2 - 4 weeks:

- **Red cell volume increases**

CARDIOVASCULAR ADAPTATIONS TO ALTITUDE

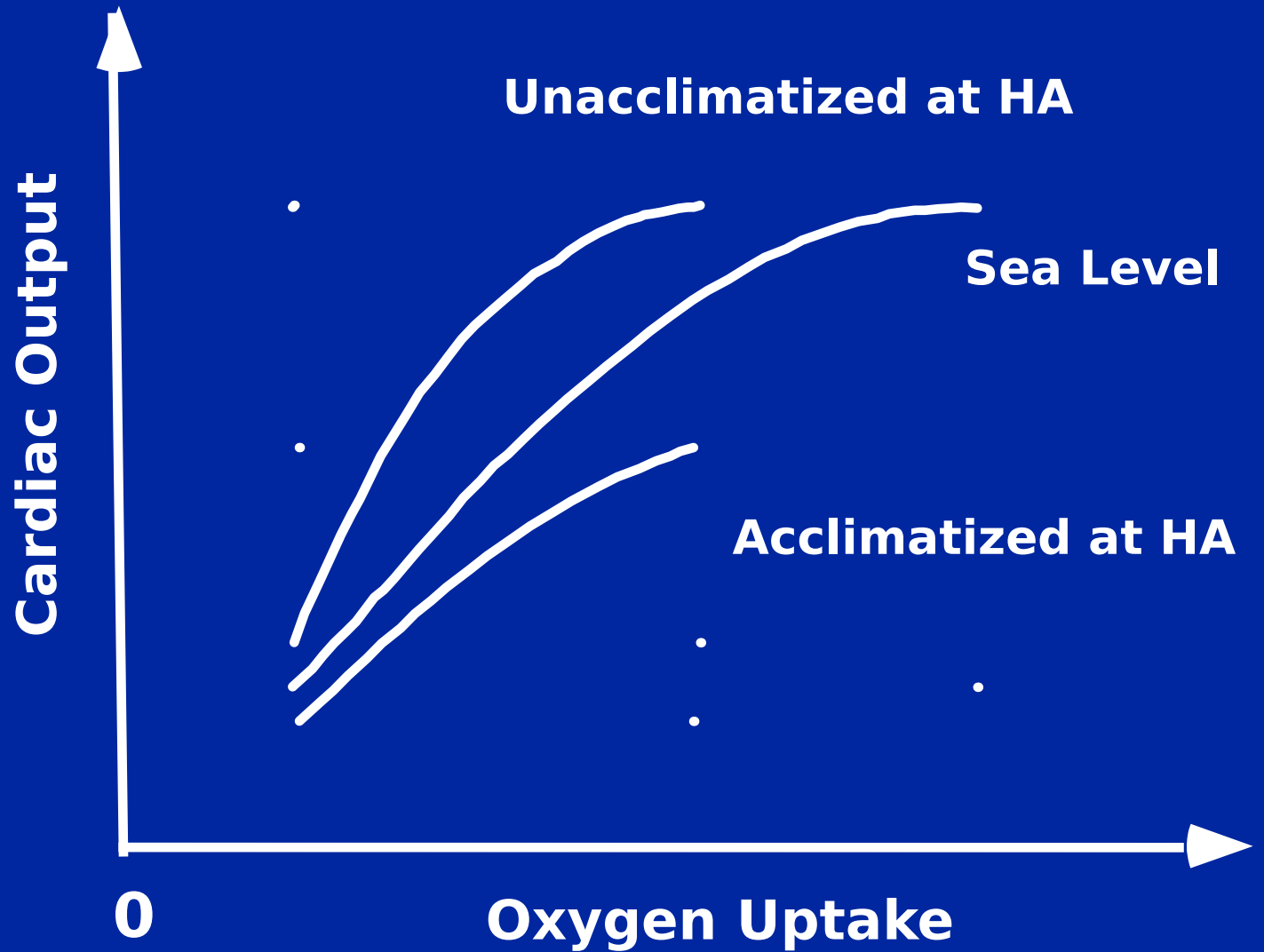
Early:

- **Increased heart rate (rest and submaximal exerc**
- **Increased cardiac output**
- **Decreased blood pressure**
- **Increased sympathetic stimulation**

3 - 12 days:

- **Heart rate unchanged**
- **Decreased cardiac output (lower stroke volume)**
- **Increased blood pressure**

Sea Level Residence Cardiac Output Response to Altitude (HA)



Young & Young, Human Perf. Physiol., 1988

LOCAL TISSUE ADAPTATIONS TO ALTITUDE

7 - 14 days:

Increased O_2 extraction:

Increased O_2 conductance (RBC to cell)

Increased muscle myoglobin

Muscle glycogen spared

Lower muscle lactate

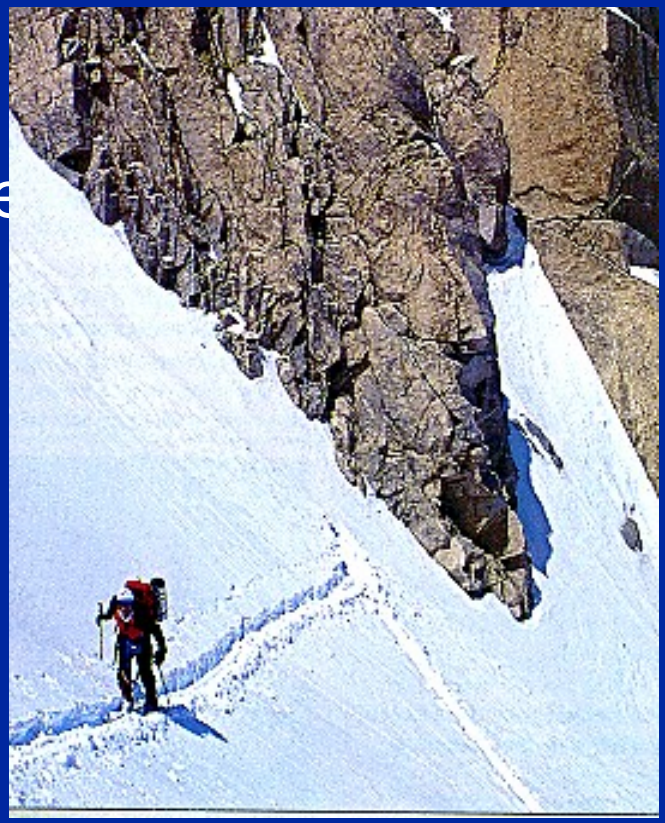
MOUNTAIN ENVIRONMENT NUTRITION

Caloric Deficit

- Increased BMR
- High Energy Expenditure
- Reduced Appetite
- Food Source

Dehydration

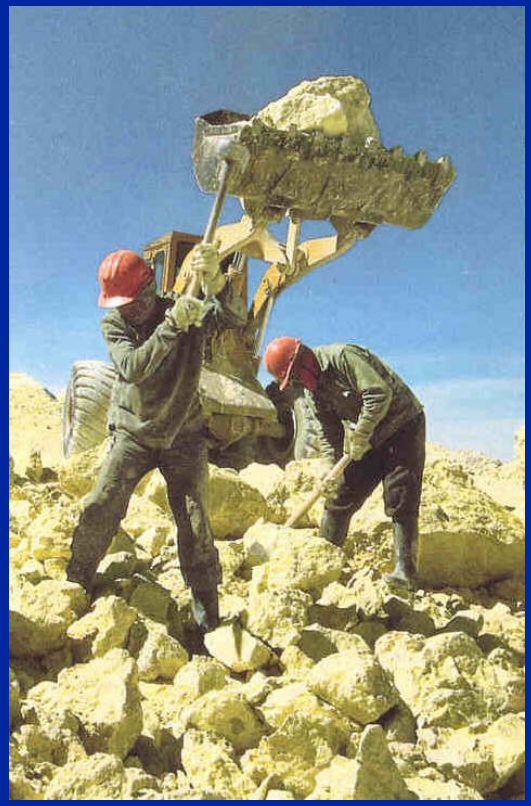
- Dry Air
- Increased Ventilation
- Reduced Thirst
- Diuresis
- Water Source



ALTITUDE ACCLIMATIZATION BENEFITS

- Well Being - *Improved*
- Mental Performance - *Improved*
- *Sleep Quality - Improved*
- Submaximal Work Performance - *Improved*
- Maximal Work Performance - *Unchanged*

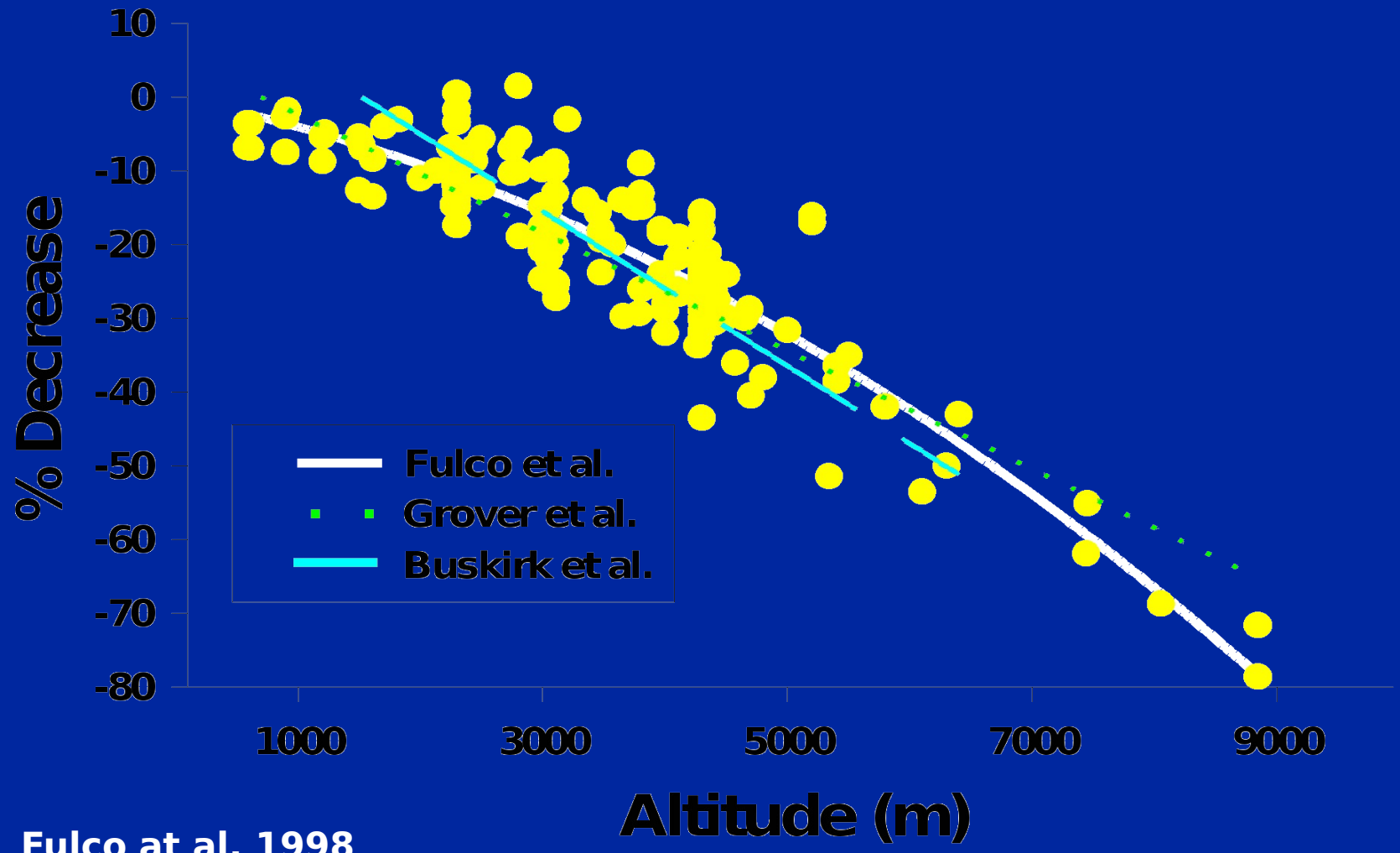
WORK PERFORMANCE AT ALTITUDE



WORK PERFORMANCE AT ALTIUDE

- Young Adults
- Healthy
- No Deterioration

VO_2 max DECLINES WITH INCREASING ALTITUDE



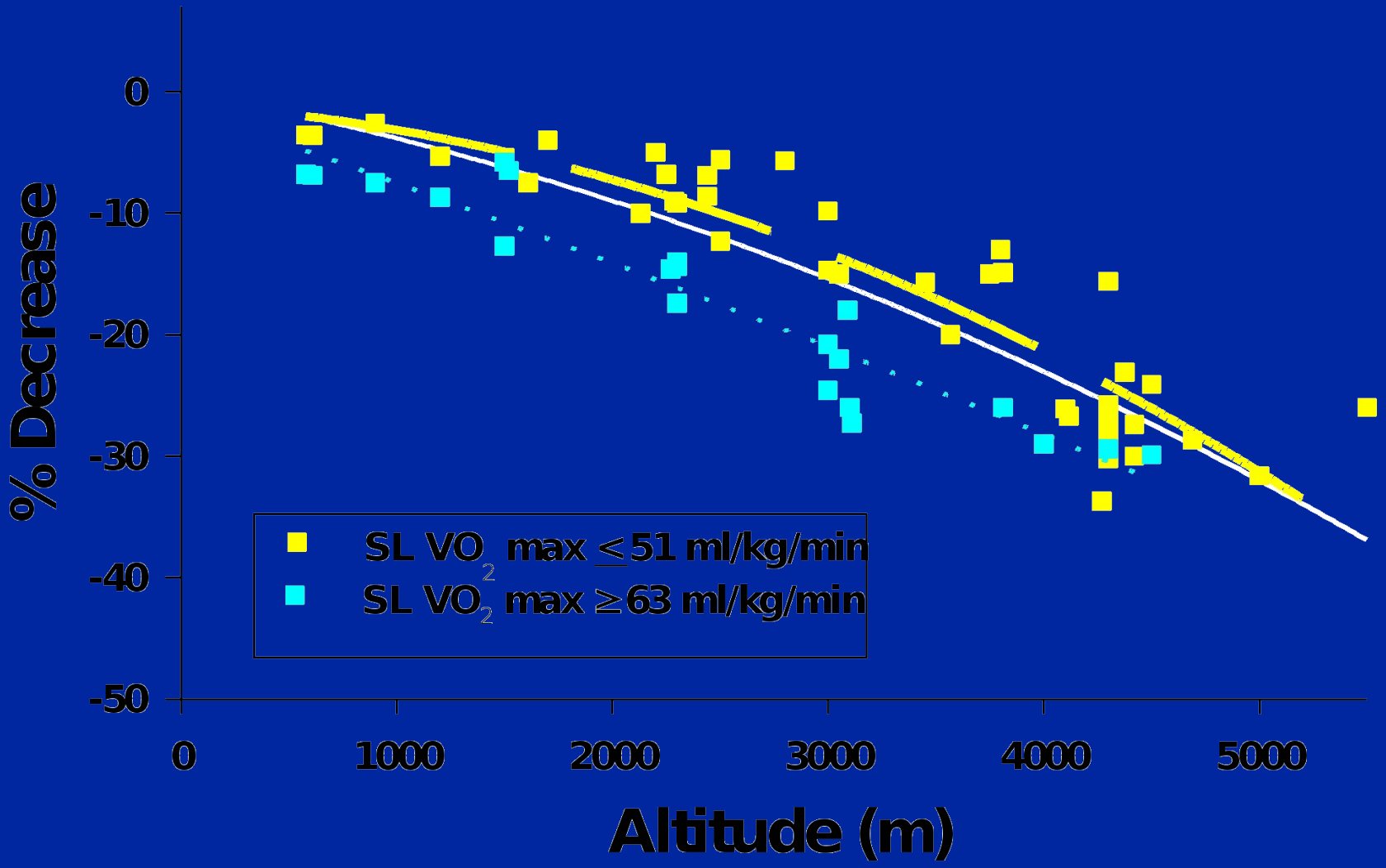
Fulco at al. 1998

VO_2 max DECREASES AT ALTITUDE FROM REDUCED ARTERIAL OXYGEN CONTENT

$$\dot{V}O_2\ max\ (ml / min) = \dot{Q}\ max\ (L / min) \times CaO_2 - CvO_2\ (ml / L)$$

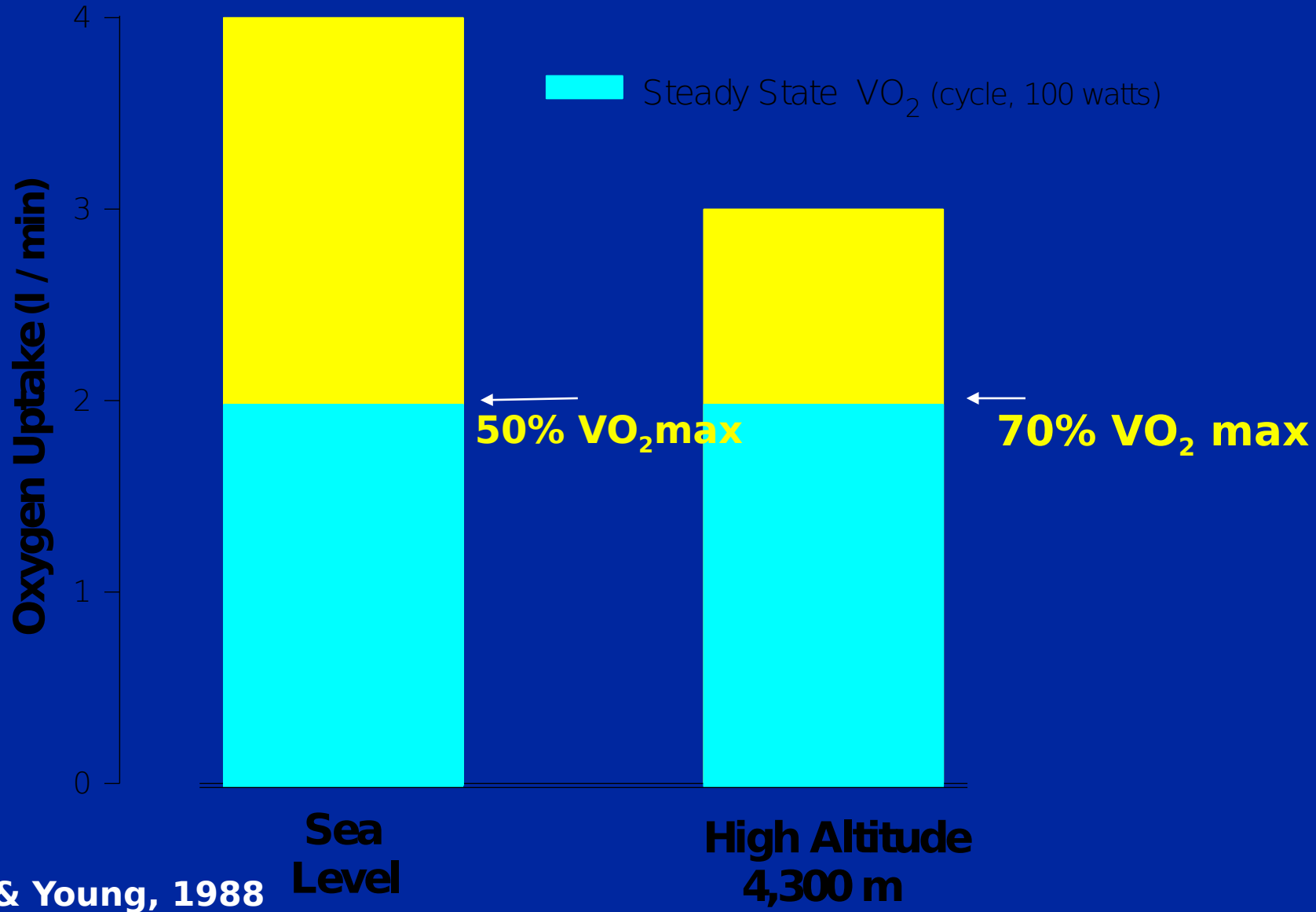
	$\dot{V}O_2$ max (ml / min)	$\dot{Q}$ max (L / min)	$CaO_2 - CvO_2$ (ml / L)
Sea Level	5580	30	186 (197 - 11)
	-28%		
4,300 m	4020	30	134 (145 - 11)

VO_2max Decreases More in High Fit Person



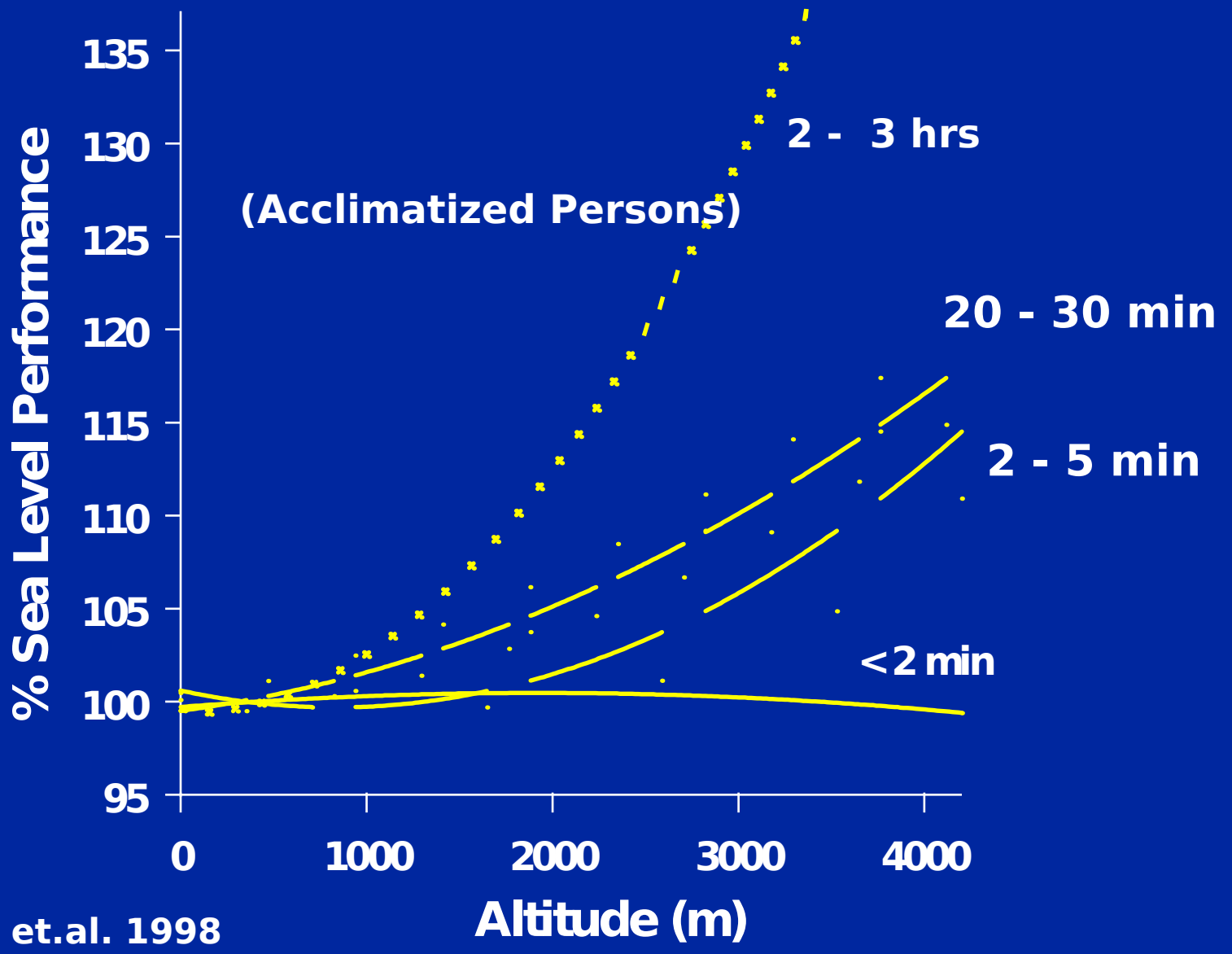
Fulco at al. 1998

ALTITUDE EFFECTS ON $\dot{V}O_2$max & RELATIVE INTENSITY



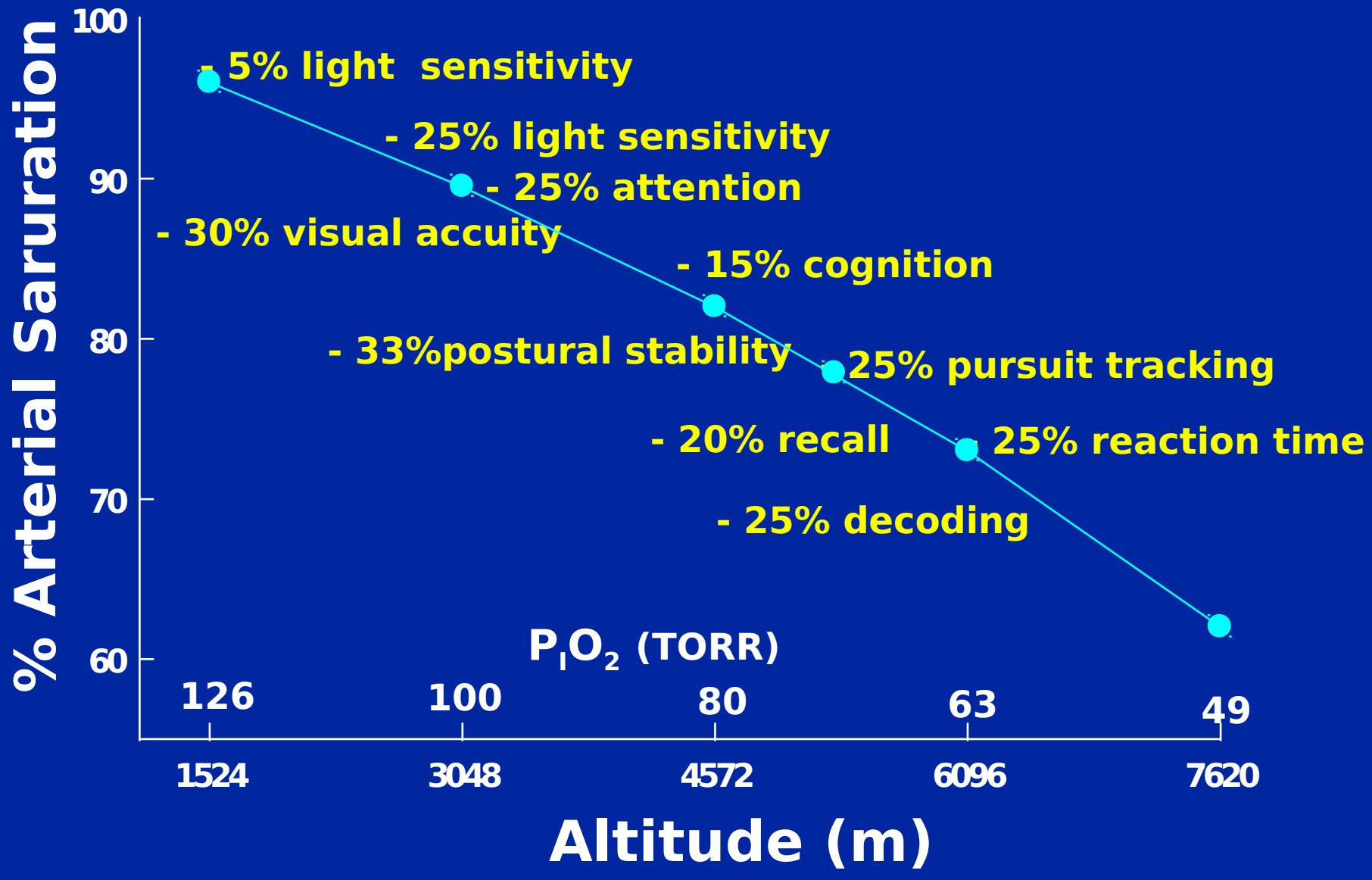
Young & Young, 1988

ATHLETIC PERFORMANCE DECREMENT RELATED TO ALTITUDE & EVENT DURATION



Fulco et.al. 1998

SENSORY & MENTAL FUNCTION DECREASES



Young, Human Performance Physiology , 1988

ALTITUDE-INDUCED MEDICAL PROBLEM

ALTITUDE- INDUCED ILLNESS

Acute Mountain Sickness

High Altitude Cerebral Edema

High Altitude Pulmonary Edema

High Altitude Retinal Hemorrha

High Altitude Peripheral Edem

ALTITUDE- INDUCED ILLNESS SUSCEPTIBILITY

- Unacclimatized state
- Rapid ascent
- Exercise or heavy physical work
- Cold
- Not gender specific
- May be greater in people < 50 yrs

ACUTE MOUNTAIN SICKNESS (AMS)

A Symptom Complex Caused by Rapid Ascent

Headache
Lassitude
Nausea
Vomiting
Weakness
Dizziness

Poor Sleep
Breathing Difficulty
Mood Swings
Decreased coordination
Oliguria
Ataxia

ACUTE MOUNTAIN SICKNESS (AMS)

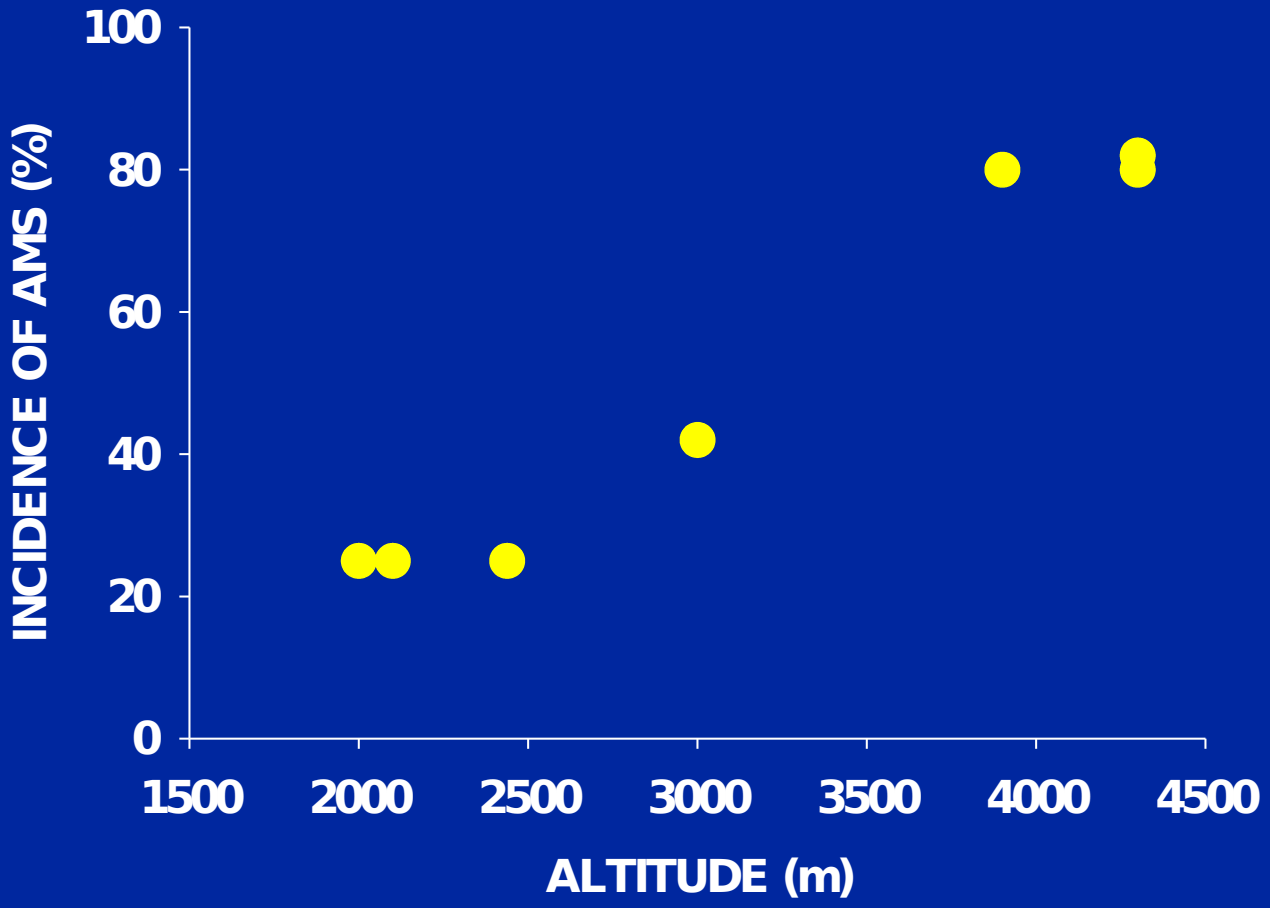
Important Points

- Preventable
- Between individual variablility
- Within individual reproducible
- Severity graded (mild - serious)
- Self-limited, but may progress to HACE, HAPE
- Differential Diagnosis

ACUTE MOUNTAIN SICKNESS (AMS)

Symptom	Time Course
ONSET:	8 - 12 hrs
PEAK:	24 - 48 hrs
RESOLUTION:	3 - 7 days

Incidence of Acute Mountain Sickness Following Rapid Ascent to Altitude



ACUTE MOUNTAIN SICKNESS (AMS)

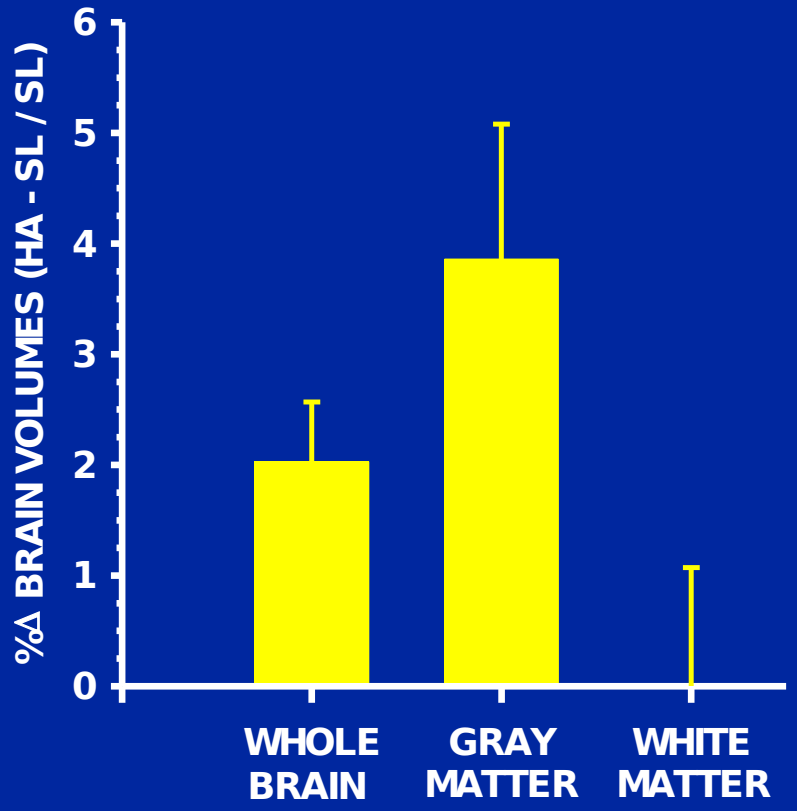
Pathophysiology

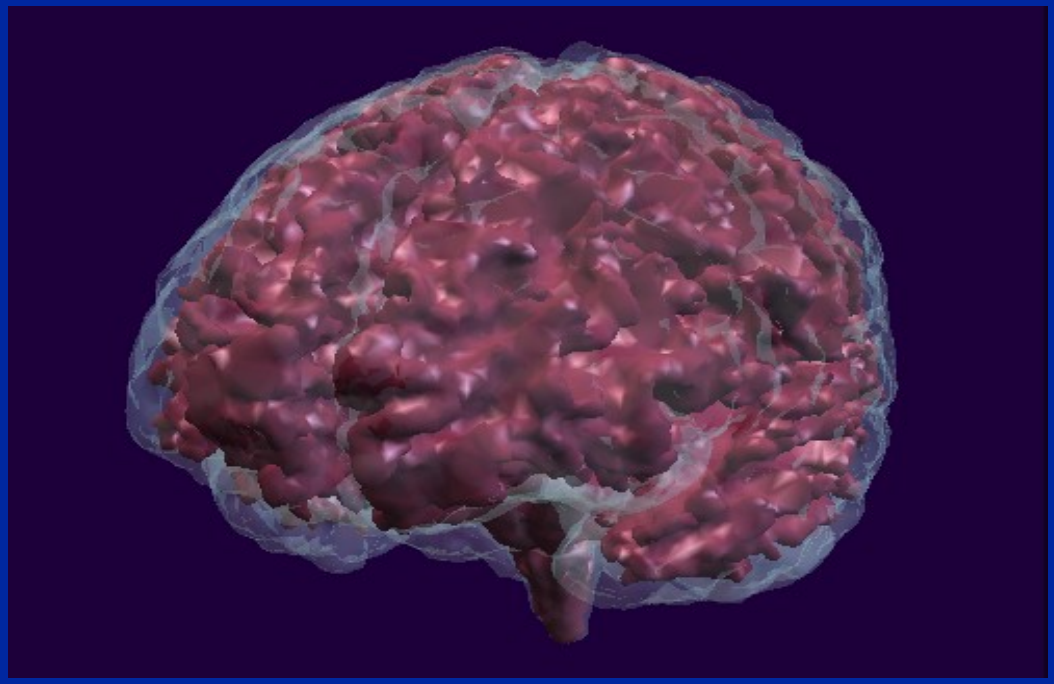
Exact Mechanism is unknowm

Brain volume increase:

- Cerebral edema?
- Increased intravascular volume?
- “Tight Compartment”

Effect of Altitude Exposure on Brain Volume





ACUTE MOUNTAIN SICKNESS (AMS)

Prevention

Staged or slow ascent above 6,000 ft

Limit exertion

Acetazolamide (Diamox)

Dexamethasone

ACUTE MOUNTAIN SICKNESS (AMS)

Treatment

- Descend
- Stop ascent
- Acetazolamide (Diamox)
- Dexamethasone
- Oxygen
- Gamow Bag

HIGH ALTITUDE CEREBRAL EDEMA (HACE)

Cerebral edema caused by high altitude

Early Phase:

AMS Symptoms
Truncal Ataxia
Mental Status Changes
Retinal Hemorrhage

Late Phase:

Motor & Sensory Neurologic Def
General Edema
Coma

HIGH ALTITUDE CEREBRAL EDEMA (HACE)

Important Points

Incidence: ~1%

Symptom onset 1 - 13 Days after Ascent

May start as AMS

Often associated with HAPE

Potentially fatal

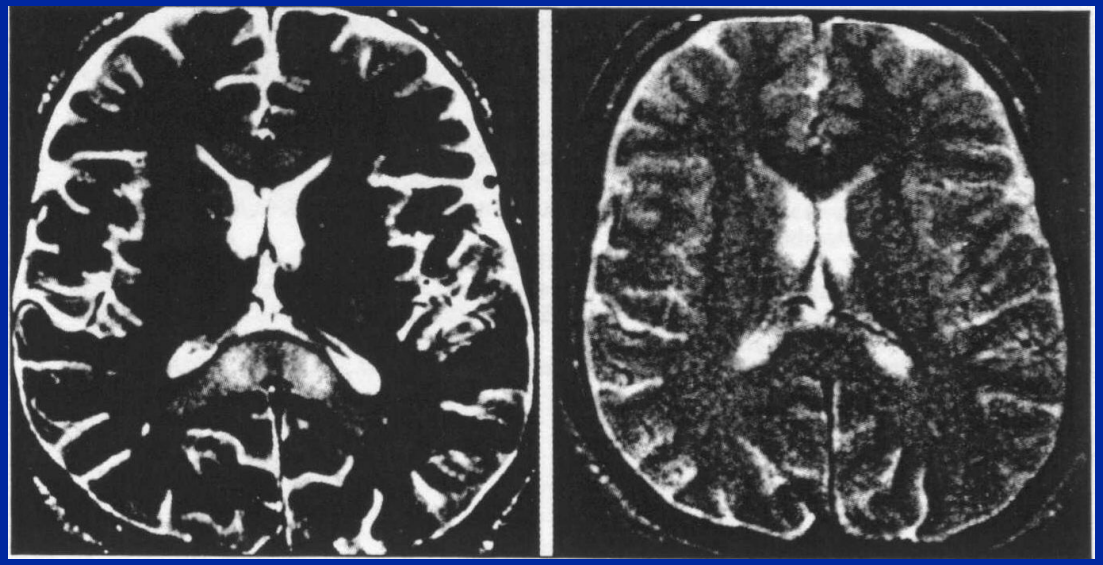
Preventable

Treatable

COMPARISON OF AMS AND HACE

AMS	HACE
Headache	Severe headache
Nausea	Nausea
Vomiting	Vomiting
Weakness	Extreme lassitude
Lassitude	Truncal ataxia
General malaise	Altered mental status
Decreased coordination	Ataxic gait
Dizziness	Generalized neurologic abnormalities
Oliguria	

HIGH ALTITUDE CEREBRAL EDEMA (HACE)



33 yr male, SL to 5200 m in 6 days,
MRI day 2 and 11 months later

MRI of acute and recovered phases of HACE.
7 of 9 patients with HACE showed intense T2 signal in white ma
areas, especially the splenium of the corpus callosum.

Hackett et al., JAMA 1998

HIGH ALTITUDE CEREBRAL EDEMA (HACE)

Prevention and Treatment

Same as AMS

Descend Immediately!

Dexamethasone

Acetazolamide (Diamox)

Oxygen

Gamow Bag

HIGH ALTITUDE PULMONARY EDEMA (HAPE)

Non-cardiogenic pulmonary edema caused by high altit

Early Phase:	**Dyspnea on exertion** **Fatigue** **Non-productive cough** **AMS Symptoms** **Rales, tachycardia, tachypnea**
Late Phase:	**Central cyanosis** **Decreased mental status** **Productive cough *(pink & frothy)*** **Coma and Death**

HIGH ALTITUDE PULMONARY EDEMA (HAPE)

Important Points

Incidence: 1 - 5%

Symptoms onset 2 - 5 days after ascent

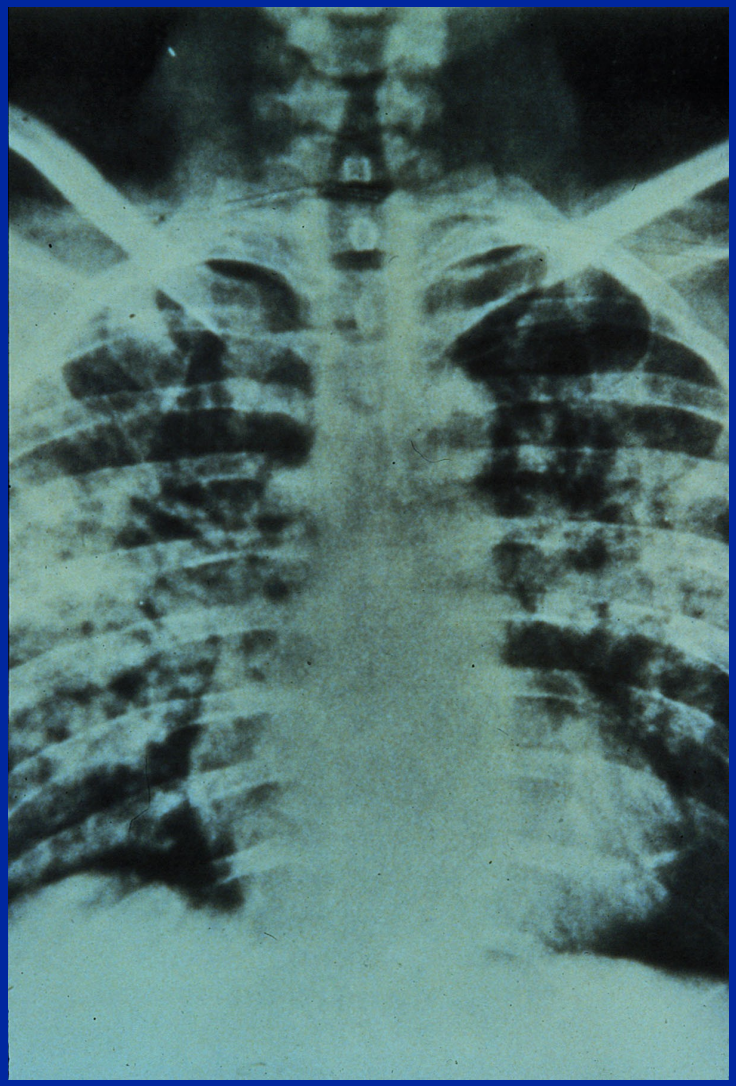
Rapid progression!!

Potentially fatal

Preventable

Treatable

HIGH ALTITUDE PULMONARY EDEMA



HIGH ALTITUDE PULMONARY EDEMA (HAPE)

Pathophysiology

Exact Mechanism is unknowm

High permeability pulmonary capillary leak

Hypoxic pulmonary hypertension

HIGH ALTITUDE PULMONARY EDEMA (HAPE)

Prevention and Treatment

Same as AMS

Descend Immediately!

Nifedipine

Acetazolamide (Diamox)

Oxygen

Gamow Bag

HIGH ALTITUDE RETINAL HEMORRHAGE (HARH)

Hemorrhagic retinopahy due to altitude exposure

Incidence: very common above 5,000 m

May be related to AMS and HACE

Can occur in absence of AMS, HACE, HAPE

HIGH ALTITUDE RETINAL HEMORRHAGE (HARH)

Prevention and Treatment

Not preventable

Usually asymptomatic

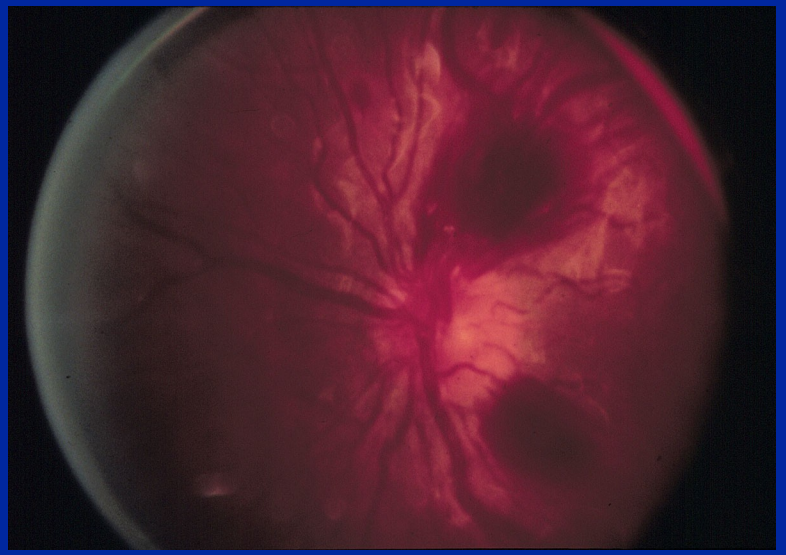
Macular location may cause blurring

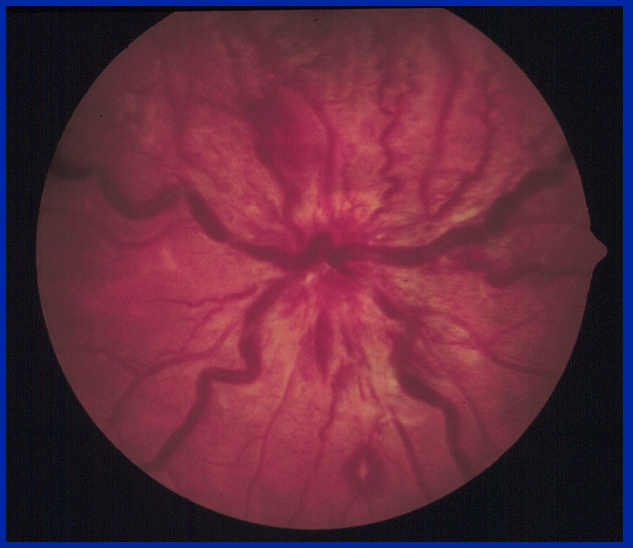
Fundoscopic exam

Resolves on descent

HIGH ALTITUDE RETINAL HEMORRHAGE (HARH)

Fundoscopic Exam





GENERALIZED PERIPHERAL EDEMA

Edema to the face and extremities due to altitude exp

Incidence: unknown

May be more prevalent in women

Can occur in absence of AMS, HACE, HAPE